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Use of Cloud Services in Functional Products: availability implications

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Abstract

The paper addresses the potential use of cloud services in Functional Products (FP) and its possible implications for availability. Further, how the implications for availability can be understood via modelling and simulation is addressed. The paper adds further specificity to literature by indicating the FP constituents for which cloud services are applicable and adequate.

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1. Introduction

The emerging trend of using cloud services [1], e.g. Software-as-a-Service (SaaS), Platform-as-a-Service (PaaS), or Infrastructure-as-a-Service (IaaS), has reached the manufacturing industry and seems appealing for providers of advanced offerings such as Product-Service Systems (PSS), Industrial Product-Service Systems (IPS^2), Functional Sales (FS) and Functional Products (FP). However, as all of the aforementioned concepts can be or are sold, wholly or partly, with a specified level of availability, one important issue that needs to be addressed is what implications the use of cloud services may have for the overall availability. To limit the scope, this paper will only address the potential application of cloud services, and in particular SaaS, in an FP context, where FP are sold as functions with a specified level of availability. According to Löfstrand et al. [2, 3], in an FP context, availability (or functional availability) can be defined as a function of maintainability and reliability, where predictions of the availability and corresponding cost are necessary.

A motivation for using cloud services is to lower costs and necessary management efforts for customers (and providers) by applying an economies-of-scale approach from the cloud service provider side. Another is that cloud services can be globally available via the internet. A further benefit is that general scalability/rapid elasticity [1], availability and cost for management of software are in most cases more attractive in a cloud service scenario compared to using in-house or outsourced services and resources. However, additional aspects of cloud computing, such as security and legal issues, need to be managed to be able to gain acceptance for the use the cloud services in an FP context. The security and legal aspects have recently been highlighted by, for instance, the vivid debate on the US Government/National Security Agency (NSA) tool PRISM, used to survey communications over the Internet, as well as the potential US Government/NSA access to customer data stored in US cloud service providers' data centres. To get a better understanding of the applicability of cloud services in an FP context, the FP concept is explained below.

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FP[1] has been defined by Lindström et al. [10, 11, 12] as integrated hardware, software, service support system and management of operation. The software component grows as the requirements for monitoring, remote management and maintenance and software upgradability become further sophisticated [13, 14]. The software is often integrated with the hardware and service support system and, depending on type of FP, can also be seen as a stand-alone entity providing its own value to the delivery of the function. The service support system is needed to keep the hardware and software operable, and the triad is combined to provide a complete function to customers [6, 15]. Alonso-Rasgado et al. [6] add that the service support system is much more than maintenance, often including decision-making, operations planning, remanufacture and education. Throughout the FP lifecycle, operation of the FP must be managed and developed.

There are numerous publications on cloud services and availability (e.g. [16, 17]), but few that concern the use of cloud services in PSS, IPS^2, FS or FP and the related implications on availability. Mont [18, p4] denotes PSS as a "*system of products, services, supporting networks and infrastructure that is designed to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models*". According to Mont [18], network and infrastructure are needed as inter-organizational changes, such as closer interaction with other actors in the product service chain, and outsourcing create the demand for intermediates, i.e. managing actor relations. Lelah and Brissaud [19] have in a conceptual manner proposed how ICT and networks can contribute to PSS in different configurations in order to get real-time (or close to real-time) information and monitoring capabilities. Instead of defining the frontiers between PSS and ICT as Lelah and Brissaud [19] have, we aim to highlight the possible and necessary integration of ICT in an FP context and the implications for availability. Karlsson et al. [20] bring up the possible use of cloud services in FP contexts for intelligent processing and querying data streams related to monitoring the operation of FP. The monitoring of operation aims to find indications of problems before they occur, and to be able to proactively manage these issues so as not to impair the level of availability. In addition, Karlsson et al. [20] state that connectivity, needed to monitor FP in real time, is a crucial and adequate provision that must be made for communications. Further use of cloud services in PSS or IPS^2 contexts is proposed by, e.g., Hosono and Shimomura [21] related to service design, Abramovici and Aidi [22] in the next-generation Product Lifecycle Management systems, and Meier and Dorka [23] regarding an IPS^2-Execution System (IPS^2-ES) for managing networks of suppliers, fluctuations in the network, adapting to suppliers and real-time planning of resources, in order to achieve robustness in manufacturing. The IPS^2-ES seems similar to the management of operation in FP proposed by Lindström et al. [11], which, among other things, addresses long-term availability matters during the operation of FP.

Currently, there is a lack of research regarding how cloud services can be used in advanced concepts such as PSS, IPS^2, FS and FP, sold with an agreed level of availability. Most of the current research (e.g. [20, 21, 22, 23]) investigates whether it is possible to use cloud services, but not the possible implications for availability. The issues addressed in this paper are the possible use of cloud services in FP, what implications their use may have for FP availability and how these implications may be understood through modelling and simulation.

2. Cloud Services in Functional Products

According to NIST [1], there are a number of deployment models for cloud services, e.g., private cloud (operate solely for one organization), community cloud (shared by organizations that have shared concerns), public cloud (available to anyone) and hybrid cloud (composed of two or more clouds). Thus, the choice of deployment model should be considered in light of the requirements from FP contexts.

In an FP context, according to Lindström et al. [11], software is often integrated with the hardware and service support system and, depending on type of FP, can also be seen as a stand-alone entity providing its own value to the delivery of the function. In addition, software supports the management of operation. Depending on availability requirements and connectivity, the software may be run locally on the site of operation from remote or distributed servers. The ICT-infrastructures needed could be the customer's internal ICT-infrastructure, the provider's, a third party's (e.g. a telecom provider/operator) or a combination of these.

Based on recent research by Lindström et al. and Karlsson et al. [10, 11, 20, 24], Table 1 outlines potential use of software in the FP main constituents: hardware, software, service support system, and management of operation. Further, Table 1 assesses the applicability/adequacy of using cloud services (low, medium, high), criticality for FP function availability (real-time, short-term, medium-term or long-term), and if there might be additional business restrictions such as legal or security constraints hindering the use of cloud services. The criticality for FP function availability of a software solution is defined as real-time if its current performance directly influences the immediate availability of the FP function, whereas it is defined as short, medium or long-term if its current performance indirectly influences the future availability of the FP function.

[1] The concept of FP has similarities with, for instance, Functional Sales [4], Extended Products [5], Total Care Products [6], Product-Service System (PSS) and Industrial Product-Service Systems (IPS^2) [7], Servicizing [8], or Service Engineering [9] in the sense of increasing the focus on soft parts such as services, knowledge and know-how, etc. additionally offered. The FP, originating from hardware aspects, has most commonalities with PSS/IPS^2, Total Care Products and Functional Sales, adding, however, additional complexity development-wise.

Table 1. Potential use of cloud services (SaaS) in FP and availability implications

FP constituent	Examples of software	Applicability /adequacy of using cloud services (SaaS)	Criticality for FP function availability	Additional business restrictions
Hardware	Operating systems, firmware, embedded/ integrated software, device drivers, controller software, micro code, data extraction, network protocols	In general low	In general real-time	Security
Software	Tools and portals, simulation/modelling/ calculation software, update/patch management systems	Low to medium	Short-term	Security
Service Support System	Monitoring system (on-line and off-line), tools for collaboration and problem solving	High	Real-time	Security
	Information systems for planning/reporting/logging of support and maintenance activities, configuration management systems	Medium	Short-term	Security
	Knowledge management systems, education/ training systems – distance education	High	Long-term	Security
Management of operation	Systems for decision making	Low to medium	Short-term	Security
	Systems for lifecycle management/product data management/financial planning/contract management/ risk management/intellectual property management/ availability management/ customer and partner relationship management	High	Long-term	Security and legal

Thus, the use of cloud services in FP seems to have great potential as long as the availability implications are kept on a level where the agreed-upon availability can be honoured.

Further, the recently coined manufacturing model Cloud Manufacturing (CMfg), which is well described by Tao et al. [25] and discussed in a PSS context by Sun et al. [26], needs to be highlighted and discussed in relation to the potential use of cloud services in FP. Tao et al. [25, p1970] conceptualize CMfg as being "*a computing and service-oriented manufacturing model developed from existing advanced models…and enterprise information technologies under the support of cloud computing, IoT, virtualization and service-oriented technologies, and advanced computing technologies. It aims to realize the full sharing and circulation, high utilization, and on-demand use of various manufacturing resources and capabilities by providing safe and reliable, high quality, cheap and on-demand manufacturing services for the whole lifecycle of manufacturing…In a CMfg system, various manufacturing resources and abilities can be intelligently sensed and connected into the wider internet, and automatically managed and controlled using IoT technologies (e.g. radio frequency identification (RFID), wired and wireless sensor network, embedded system). Then, the manufacturing resources and abilities are virtualized and encapsulated into different manufacturing cloud services (MCSs) that can be accessed, invoked, deployed, and used on-demand based on knowledge by using virtualization technologies, service-oriented technologies, and cloud computing technologies" (sic).* In addition, the MCSs can be classified and aggregated in order to construct the wanted MCS, which may be used under a certain part or the whole of the lifecycle of the manufacturing process targeted. Thus, it seems like the CMfg model could be used when manufacturing some FP constituents and later on as well during the operation of FP, forming a sub-system or similar, if the FP is used in a manufacturing context. Likewise, adequate FP could be used as a manufacturing resource in the CMfg model where the manufacturing ability of high function availability is preferred or necessary.

3. Availability implications from use of cloud services in Functional Products

There are a number of differences between local and cloud software that have implications with regard to availability of an FP. Cloud services have the additional failure mode of loss of connectivity across the delivery network. Different cloud services utilized within a single FP and across different FP may also utilize common networking and computing resources. This may be the case even between services provided by independent third parties, since they may run on common infrastructure (e.g. due to outsourcing). In contrast, local software is deployed on independent and isolated computing resources. The existence of shared resources between cloud services utilized within an FP design introduces the risk of common-cause failures that could lead to simultaneous loss of availability of those services within a single product and across different products. Depending on the reliability structure of the FP design, dependencies between failures of software services with real-time criticality (see Table 1) to the FP function could influence the availability of that function. The loss of a software service with real-time criticality to the FP function across multiple customers simultaneously could cause a sudden increase in demand on the FP service support system and an increase in the time before availability is restored. For software with short to long-term criticality to FP availability (see Table 1), temporary losses of availability, as long as they are not excessively frequent or long in duration, will have negligible impact on availability.

The availability of cloud services is not necessarily poor in comparison to local software, as supported by the statement by Armbrust et al. [16, p54] "*organizations worry about whether utility computing services will have adequate availability, and this makes some wary of cloud computing. Ironically, existing SaaS products have set a high standard in this regard...*". Indeed, cloud services offer some unique possibilities for increasing availability, such as the ability to rapidly scale resources to meet peaks in demand, to recover from failures dynamically (e.g. by switching deployment to another data centre in the case of catastrophic failure), and continuous deployment of upgrades and bug fixes. However, cloud software running on public networks can be susceptible to hostile attacks, such as denial of service, which could have a negative impact on availability. The use of cloud services from third parties also introduces third-party risk, such as the possibility that the provider could go out of business. A final relevant difference is that the use of cloud services increases the ease with which data can be collected and collated from multiple products operating at multiple customer sites and expands the computing resources available to process this data. The collection, collation and analysis of data across FP through a cloud service should facilitate availability growth over time as the FP is operated, e.g. data stream monitoring might enable the pre-emptive replacement of components from the same faulty batch across multiple FP when detected within a subset of those in operation.

3.1. How to understand the availability implications via modelling and simulation

The provider of an FP needs to be able to simulate the combined hardware and service support system in order to optimize for overall FP availability and support costs [2, 27]. As indicated in section 2, there is a great potential for use of cloud services in FP, yet it is important to understand the availability implications. The modelling and simulation approach presented by Löfstrand et al. [3] is ideally suited to understanding and quantifying these implications for software solutions with real-time criticality to FP availability. For example, when having an agreed-upon level of availability regarding the operation of FP, this approach could be used to investigate whether using one provider for a specific cloud service is enough, or if two or more should be used, as suggested by Armbrust et al. [16]. For software solutions with longer-term criticality to availability, modelling and simulation is less applicable, since formally representing the indirect and future influence they have on availability is often extremely difficult.

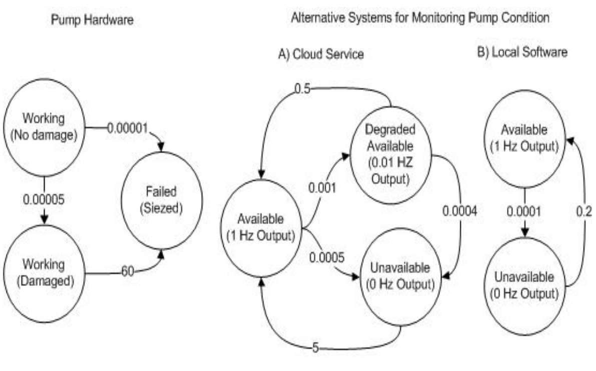

Figure 1. Availability models for pump system example.

Within the modelling approach presented by Löfstrand et al. [3], the availability of a software solution, either local or cloud service, can be represented through a state space model that describes its possible states and the transitions between them. These models can then be integrated with models of other hardware and software components within reliability structure models, i.e. fault trees [28], to describe the relation between the component availabilities and the availabilities of higher level systems within the FP. For models of hardware FP constituent software (see Table 1), this will include integration within the reliability structure model that represents the overall FP availability. The models of service support system FP constituent software (see Table 1) will be integrated within the maintenance strategy and process models to represent their relation to the triggering and execution of maintenance processes respectively. For example, consider a pump system that usually enters a damaged state when failure is imminent and is condition-monitored by software that analyses a data stream for the pump oil particle count and reports with a certain frequency whether or not the pump is in the damaged state. The maintenance strategy is to stop and repair the pump hardware if pump damage is indicated (predictive maintenance) or, at greater cost and time, replace it if it fails (corrective). The modelling and simulation approach could be used to evaluate the implications of using a cloud-based monitoring software, which is more likely to be degraded or unavailable but recovers availability faster than a local software, on the pump availability and support costs. Figure 1 shows the availability models (where all transitions are exponentially distributed and the rate per hour is indicated) for the pump hardware system and alternative software solutions (cloud or local) for the monitoring software.

4. Discussion and Conclusions

The results of the paper indicate that the use of cloud services in FP has great potential as long as the availability implications are understood and found to be acceptable. The paper adds further specificity to literature by indicating the FP constituents where cloud services are applicable and adequate, outlining the potential implications to overall FP availability and describing how these implications can be understood via modelling and simulation. The results are also applicable to certain PSS, IPS^2 and FS as well, where software may be integrated in the products/hardware as well as in associated services. Additional business restrictions, such as legal or security constraints, need to be managed and mitigated to gain acceptance for the use of cloud services in FP contexts where, e.g. confidential or sensitive personal information is communicated, processed or stored in cloud services. A probable outcome of the surveillance activities by the US Government/NSA, the PRISM tool, and other similar initiatives is that stronger encryption algorithms and keys will be applied to communications over the internet as well as for encryption of data at rest. Further, backdoors implemented in software by technology providers (e.g. that enable the bypassing of normal login procedures) and the key escrow practice (e.g. that certain encryption keys are known by government agencies) are also likely to be strongly challenged.

Further, the recently coined manufacturing model CMfg and FP can, where appropriate, have use for each other, and in particular the CMfg could use adequate FP as manufacturing resources where the manufacturing abilities high availability and a function are wanted.

In conclusion, if the availability and additional business restrictions are properly managed, the use of cloud services in FP contexts provides opportunity to improve the wanted win-win situation between the FP provider and customer via improved economies-of-scale, scalability/rapid elasticity, availability, as well as less complex and decreased costs for management of software.

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